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Human-Centered Future: The Rise of Industry 5.0 in Corporate Sustainability Literature

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Abstract: In the second quarter of the 21st century, Industry 5.0 is considered as the most advanced stage of the industrial revolution, where the interaction between people and smart technologies has reached a new level. This assessment is not limited to the digital transformation of production processes, but also shaped by multidimensional sustainability elements such as environmental sensitivity, social benefit and ethical responsibility. The concept of Industry 5.0 seeks to build a manufacturing ecosystem grounded in sustainability and human-centric principles. The aim of this study is to reveal the current research trends in the international academic literature within the framework of the keywords "Industry 5.0" and "Sustainability" and to analyze the areas in which this conceptual framework is concentrated through bibliometric data. Building on this context, a total of 664 English-language scientific publications published between 2020 and 2025 in the Web of Science (WoS) Core Collection database were included in the scope of the analysis. The retrieved data were processed using RStudio Biblioshiny and VOSviewer software, and the publications were systematically evaluated according to their distribution across research fields, open access status, funding institutions, ongoing projects, influential conferences, leading journals, and prolific authors. The findings reveal that engineering, computer-related fields, and environmental sciences stand out as the disciplines contributing most to this area, while the fact that 71% of the publications are open access has gained particular attention. Furthermore, it was identified that funding bodies originating from the European Union and China provide the majority of financial support for this research domain. International conferences and publishers such as IFIP, IEEE, and ACM are among the most prominent platforms where the research is disseminated. As a result of the research, it is seen that the themes of Industry 5.0 and sustainability are met with increasing interest in the scientific literature; this interest is supported by multidisciplinary collaborations, global research funds and open access policies. This study contributes to identifying gaps in the literature and possible future research directions by revealing how Industry 5.0 is positioned in the context of sustainability.

Keywords: Industry 5.0, Sustainability, Bibliometric analysis

Introduction

Since the industrial revolution, technological advances have not only transformed production processes, but also radically affected social structures, labor relations, and understanding of sustainable development (Schwab, 2016). Today, the concept of Industry 5.0 aims to develop more resilient and sustainable production systems by bringing together human creativity and the capabilities of advanced technologies (Machado & Davim, 2023). The transition to Industry 5.0 has become possible with the deepening of cooperation between humans and smart technologies (Xu et al., 2021). While Industry 4.0 is basically shaped around automation, the internet of things, and digital integration, Industry 5.0 emphasizes a harmonious cooperation between artificial intelligence and human skills (Machado & Davim, 2023).

At the same time, unlike Industry 4.0, Industry 5.0 does not only focus on production efficiency; It contributes to the construction of a sustainable and human-centered future by adopting a human-centered approach that

prioritizes ethical values, social inclusiveness, environmental responsibility and the well-being of employees (Güdek, 2023). While this transformation takes human-machine collaboration to a further level, it also requires a radical change in the strategic orientations of institutions. Especially when considered within the framework of "corporate sustainability"; Industry 5.0 requires businesses to integrate their economic gain goals with social responsibility and environmental ethics (Elkington, 1998; Carroll & Shabana, 2010).

Corporate sustainability requires addressing economic, environmental and social dimensions with a holistic approach in line with the United Nations Sustainable Development Goals (UN SDGs) (UN, 2015). In this context, it is argued that Industry 5.0 is not only a technological evolution but also a structural paradigm that will contribute to sustainable development. Although the number of academic publications addressing these two concepts - Industry 5.0 and corporate sustainability- has increased in recent years, it is seen that the current literature has some limitations in terms of thematic diversity, theoretical depth and empirical basis (Palumbo et al., 2022; Dacre et al., 2024).

In this context, the main purpose of the study is to examine the academic accumulation developing on the axis of Industry 5.0 and corporate sustainability with a systematic and bibliometric analysis method, to map the existing knowledge clusters and to reveal the intersection points of these two concepts in the literature. In this context, the analyses will be based on the Web of Science database and conceptual clusters, publication trends and author collaborations will be analyzed using bibliometric analysis tools such as VOSviewer and CiteSpace (van Eck & Waltman, 2010; Chen, 2006).

The originality of the study lies in its interdisciplinary approach to evaluating the complementary and sometimes tense relationship between Industry 5.0 and sustainability issues. In addition, this literature mapping study aims to direct scientific knowledge production by defining thematic focus areas that will form the basis of future qualitative and quantitative research (Small, 1973; Aria & Cuccurullo, 2017).

On the other hand, recent systematic reviews in the literature show that the relationship between Industry 5.0 and sustainability is still at an early stage and has methodological limitations. For example, in their systematic review analyzing studies published between 2019 and 2022, Baig and Yadegaridehkordi (2024) emphasized that Industry 5.0 has a great potential to contribute to sustainability goals; however, this potential has not yet been addressed in a fully holistic and systematic manner in the scientific literature. Studies show that technologies such as the Internet of Things, artificial intelligence, and collaborative robots stand out in sustainability-oriented applications; however, human-centered production systems are the most common research theme. These findings support the analytical basis on which our study is based and indicate that Industry 5.0 should be investigated more comprehensively in the context of corporate sustainability (Baig & Yadegaridehkordi, 2024).

Conceptual Framework

Paradigm Shift in Industry 5.0

The distinctive aspect of Industry 5.0 is that it aims to balance the high automation capacity offered by machines and artificial intelligence with human creativity and values. In this context, Industry 5.0 represents not only a technological evolution, but also a paradigm shift that prioritizes ethical, environmental and social responsibilities (Javaid et al., 2022). Especially in terms of its relationship with sustainability, Industry 5.0 is evaluated with a holistic approach that includes goals such as reducing the carbon footprint in production processes, adopting circular economy principles and using resources more efficiently (Santos et al., 2023). However, it is stated in the literature that this relationship has not yet fully matured and the scope of the research is limited. In fact, the systematic review conducted by Baig and Yadegaridehkordi (2024) shows that the studies on Industry 5.0 and sustainability remain largely at the conceptual level and that data for practice are insufficient. Most of the studies emphasize human-centered technological developments, but a significant portion of these studies are based on limited sample groups and lack long-term impact analyses. In this context, the need for empirical findings on how sustainable development goals can be more effectively integrated with Industry 5.0 technologies is increasing. When the thematic distribution of the studies is examined, it is seen that four main headings such as robotic advancement, sustainability in higher education, human-centeredness and ecosystem development stand out. These research axes are of critical importance in terms of making sense of the multidimensional structure of Industry 5.0 (Baig & Yadegaridehkordi, 2024).

Industry 5.0 aims to go beyond the Industry 4.0 paradigm, which is based on digitalization and automation, and restructure technology with a human-centered approach. This new approach prioritizes not only production

efficiency, but also human values such as ethical responsibility, social inclusiveness and environmental awareness (European Commission, 2021). In the literature, Industry 5.0 is defined as a production model that focuses on people, integrating with individuals' creativity, decision-making competencies and problem-solving skills (Güdek, 2023).

Technologies such as cyber-physical systems, artificial intelligence, the internet of things (IoT) and big data, which came to the fore in the Industry 4.0 era, are also used in Industry 5.0, but the purpose of application of these technologies is different. In this context, technology is no longer considered only as a productivity tool, but as a tool that serves to increase social welfare. The concept of "social benefit-oriented technology" stands out as the basic structure of this transformation and is directly associated with sustainable development goals (Yıldız & Alan, 2025).

Industry 5.0 is not only considered as a digital transformation but also as a comprehensive socio-technical evolution. In this approach, technology is designed and implemented in a way that is sensitive to the needs of the individual and society. As stated in the framework report published by the European Commission (2021), the three basic principles of Industry 5.0 are resilience, sustainability and human-centeredness. Similarly, Palumbo et al. (2022) argue that this new industrial era should not be limited to industrial production alone, but that social justice, environmental responsibility and individual well-being should be integrated into a holistic production system.

This paradigm shift requires businesses to abandon their traditional strategies based solely on profit maximization and adopt multi-dimensional strategies that also take into account social, environmental, and governance impacts. Carroll and Shabana's (2010) corporate social responsibility theory and Elkington's (1998) "triple bottom line" model are frequently used theoretical frameworks to explain this transformation. Accordingly, Industry 5.0 is not considered a technology-based transformation; it is considered a value-based restructuring process.

Corporate Sustainability Approaches

Corporate sustainability is a holistic management approach that aims to create long-term value by considering not only the economic interests of businesses but also their environmental responsibilities and social impacts (Dyllick & Hockerts, 2002). This approach, which goes beyond traditional corporate performance measures, requires evaluating economic, environmental and social dimensions simultaneously with the Triple Bottom Line (TBL) model (Elkington, 1998). The concept of corporate sustainability has gained importance since the 1990s with the increase in environmental crises, social inequalities and demands for corporate transparency. This paradigm, which is the reflection of sustainable development principles in the business world, has ceased to be an approach focused solely on environmental or social responsibility; it has transformed into a corporate strategy integrated with risk management, strategic management, stakeholder relations and innovation (Bansal & DesJardine, 2014).

The United Nations Global Compact and the Sustainable Development Goals (SDGs) are among the important frameworks that encourage the global adoption of corporate sustainability (United Nations, 2015). In this context, a governance approach has emerged in which companies are accountable not only to their shareholders but also to all stakeholders – employees, customers, suppliers, local communities and environmental systems (Freeman et al., 2007).

In the literature, sustainability approaches have been conceptualized across different dimensions. Rame et al. (2024) emphasize that Industry 5.0 embodies both reactive and proactive characteristics, thereby focusing industrial development on two fundamental axes. This perspective highlights that Industry 5.0 is not merely a structure responding to existing problems but also one that provides a forward-looking and strategic vision. Similarly, Ghobakhloo (2022) draws attention to the importance of reactive and proactive decision-making processes in supply chains, noting that these processes play a critical role in enhancing firms' flexibility, adaptability, and sustainability capacities. Indeed, these findings suggest that considering proactive and reactive approaches together within Industry 5.0 research offers significant contributions at both theoretical and practical levels. In addition, Hahn et al. (2015) analyze the effects of sustainability practices on organizational tensions and decision-making processes, indicating that corporate sustainability is a multidimensional art of balance.

Corporate sustainability is directly related not only to environmental performance but also to long-term competitive advantage and business model transformation. In this direction, developing conceptual structures

are being re-evaluated together with transformational technological paradigms such as Industry 5.0, and an increasing intersection between these two areas is observed (Palumbo et al., 2022).

Therefore, the human-centered vision of Industry 5.0 can be redefined in harmony with the ethical, inclusive and participatory principles of corporate sustainability. Institutional structures that minimize the social and environmental impacts of technological developments, while at the same time prioritizing human well-being and ethical sensitivity, will play a key role in achieving sustainable development goals (Carroll & Shabana, 2010; Gudek, 2023)

The Intersection of Industry 5.0 and Sustainability: A Critical Review of the Literature

The intersection of Industry 5.0 and sustainability requires that today's production paradigms be restructured not only on the basis of technological efficiency, but also within the framework of ethical responsibility, environmental awareness and social inclusiveness. In this context, Industry 5.0 offers an approach that aims to integrate technological advances with social benefit, environmental balance and long-term resilience by addressing production processes with a human-centered approach (European Commission, 2021). There is a growing interest in the literature on the extent to which Industry 5.0 overlaps with sustainability principles. In particular, themes such as human-centeredness, flexibility, durability, and environmental sustainability are considered among the basic components of Industry 5.0, and many studies have been conducted in line with these elements (Bonilla et al., 2018; Xu et al., 2021). However, existing research is mainly concentrated on limited conceptual or technology-focused areas; and has deficiencies in terms of interdisciplinary approach, applied sample diversity, and methodological diversity (Palumbo et al., 2022).

These shortcomings make it difficult to evaluate the relationship between Industry 5.0 and sustainable development goals holistically; they clearly reveal the need for the concept to be addressed with more systematic and empirical foundations at both theoretical and practical levels. For example, in a recent systematic review conducted by Baig and Yadegaridehkordi (2024), it was stated that although human-centered technological developments are frequently addressed in the literature, a significant portion of these studies are limited to limited samples, single sectors, and conceptual repetitions.

When the literature is examined, Industry 5.0 is defined as a period in which advanced technologies such as artificial intelligence, the internet of things (IoT), cobots (collaborative robots) and big data are redesigned in line with human well-being (European Commission, 2021), while some other studies take a critical stance on the extent to which these technologies are integrated with corporate sustainability goals (Jarrahi, 2018). Indeed, Baig and Yadegaridehkordi's (2024) systematic review emphasizes the potential of Industry 5.0 for application in sustainability, but shows that the existing literature is not yet mature in terms of quantity and quality. The authors state that human-centered technological developments stand out in the 46 studies they analyzed, but a significant portion of these studies were conducted with limited samples and did not produce concrete outputs based on applied studies. It was also revealed that the research themes in the literature can be grouped under four main headings, which are robotic progress, sustainability in higher education, human-centeredness and ecosystem development, respectively. These findings clearly reveal the need for more in-depth, thematically categorized and systematic approaches to the relationship between Industry 5.0 and sustainability (Baig & Yadegaridehkordi, 2024).

While current studies on sustainability focus on the opportunities offered by Industry 5.0 for environmental sustainability, the ecological risks brought about by this transformation are not addressed comprehensively enough. In particular, issues such as carbon footprint, increase in energy consumption, and environmental impacts of digital waste are discussed at a secondary level in the current literatüre (Le, 2022). This situation shows that not only Industry 5.0 is directed towards environmentally friendly technologies, but also the environmental side effects of these technologies should be analyzed more deeply.

Similarly, some structural gaps stand out in the social sustainability dimension. In particular, issues such as the effects of digitalization on the workforce, employee well-being, digital inequality and psychosocial health are still relatively neglected; empirical and theoretical analyses on the consequences of technological advances on humans remain limited (Ford, 2021). In this context, Industry 5.0 must not only be a tool that increases production efficiency, but also a carrier of policies sensitive to social justice and human dignity.
From a corporate sustainability perspective, it is seen that Industry 5.0 is mostly defined with technology-centered strategies and is designed with the assumption that these strategies will directly serve sustainable development goals. However, these approaches often lack ethical dimensions. It is observed that normative

concepts such as digital rights, justice, privacy, transparency and human dignity are not systematically integrated into the literature (Zamany et al., 2024). Therefore, holistic approaches are needed that evaluate sustainability and technology not only through technical tools but also in the context of ethical and human values.

Finally, the bibliometric analyses conducted reveal that thematic integrity and interdisciplinary transition are still weak in the Industry 5.0 and sustainability literature (Yan, 2023). The concentration of conceptual clusters in a limited number of focuses shows that this field is an immature research area. In this direction, future academic studies should be designed not only at the level of technological applicability, but also to take into account ethical, socio-ecological and cultural dimensions. This multi-dimensional approach will contribute to the human-centered and sustainable transformation envisaged by Industry 5.0 being established on a more realistic and effective basis.

Method

In this study, the bibliometric analysis method was preferred to examine the trends of scientific publications on Industry 5.0 and sustainability and to reveal the structural features of the literature. Bibliometric analysis is a systematic approach that allows the quantitative evaluation of scientific production in a specific research field and is a frequently used method in identifying developments, gaps and trends in the literature (Donthu et al., 2021). The Web of Science (WoS) Core Collection database was selected as the data source in the study. The "topic" field was searched using the keywords "Industry 5.0" and "Sustainability" together, and the resulting publications consisted of 664 scientific publications published between 2020 and 2025. Research articles, review articles, book chapters and conference proceedings were included in the scope of the analysis. In the analysis process, variables such as publication types, annual publication trends, number of authors, citation amounts, keyword frequencies, journals published, funding organizations, productive authors and countries were systematically examined. In addition, structural indicators such as keyword clusters, author collaboration networks, country and institution-based distributions were also comprehensively evaluated.

Two main tools were used for data analysis and visualization: the Bibliometrix R package (Aria & Cuccurullo, 2017) and the VOSviewer software (van Eck & Waltman, 2010). Annual production trends, basic bibliometric indicators and keyword analyses were performed with Bibliometrix, while collaboration networks between authors, countries and institutions, keyword matches and citation clusters were visualized with VOSviewer. Thanks to this methodological approach, scientific production in the field of Industry 5.0 and sustainability was analyzed from an interdisciplinary perspective, supported by both quantitative data and visual maps.

Results

In this bibliometric study prepared with the theme of Industry 5.0 and sustainability, 664 articles belonging to the years 2020–2025 were obtained from the Web of Science (WoS) database. 582 of these articles were research articles, 41 were reviews, 12 were book chapters, and It was published in the form of 29 conference papers. The publications were published from 402 different sources and were created by a total of 1961 different authors. The average number of publications per author in the studies was 0.331, and the average number of authors per publication was determined as 4.15. The total number of citations to the publications was 8032, which shows that the average citation per article was 15.41. These data clearly reveal the interdisciplinary nature and increasing scientific interest in Industry 5.0 and sustainability in Table 1.

Between 2020 and 2025, a total of 664 articles were retrieved from the Web of Science database using the keywords "Industry 5.0" and "Sustainability." Among these, the top 20 most-cited studies are listed in Table 2. The article entitled *"Industry 5.0: Prospect and Retrospect"* by Uzun et al. (2022) ranks first with 446 citations. This study provides a comprehensive discussion of the human-centered nature of Industry 5.0 in relation to technological transformation. Lu et al. (2022), in their work *"A Perspective on Human-Centered Production: Industry 5.0,"* examined how human well-being can be prioritized in production systems and ranked second with 321 citations. The study *"The Industry 5.0 Framework: Sustainability and Integration"* authored by Ivanov (2023) focuses on the integration of Industry 5.0 into sustainability and resilience policies, receiving 290 citations and ranking third. Adel's (2022) publication *"Solutions and Challenges in the Industry 5.0 Society of the Future"* made significant contributions in terms of societal impacts and ethics-oriented transformation, with 273 citations, ranking fourth. Collectively, these studies demonstrate that Industry 5.0 should be regarded not merely as a technological revolution but also as an instrument of social, ethical, and sustainable transformation.

Table 1. General characteristics of articles on "industry 5.0 and sustainability"

Examined Years	2020- 2025
Publication Type	Number (% of Total)
Research Articles	582 (57.8%)
Reviews	41 (15.6%)
Book Chapters	12 (0.4%)
Conference Papers	29 (2.0 %)
Total Publications	664 (100%)
Publication Source	529
Number of Authors' Keywords	2061
Average Citations per Article	15.41
Average Annual Citations	1.71
Single-Author Articles	38 (5.7%)
Multi-Author Articles	630 (94.3%)
Total Number of Authors	2019 (100%)
Articles per Author	0.331
Co-authors per Article	4.15
Collaboration Index	3.42

Table 2**.** The 20 most cited articles on "industry 5.0 and sustainability"

Author(S), Year	Article Title	Journal Name	Citation
Uzun et al. (2022)	Industry 5.0: Prospect And Retrospect	Journal Of Production Systems	446
Lu et al. (2022)	A Perspective On Human-Centered Production	Journal Of Production Systems	321
Ivanov (2023)	The Industry 5.0 Framework: Sustainability And Integration	International Journal Of Production Research	290
Adel (2022)	Solutions And Challenges İn The Future Industry 5.0 Society	Journal Of Cloud Computing	273
Bednar and Welch (2020)	Socio-Technical Perspectives: Sustainable Systems	Frontiers İn Information Systems	183
Ghobakhloo and Iranmanesh (2022)	Contributions Of Industry 5.0 To Sustainable Development	Sustainable Production And Consumption	177
Mourtzis and Angelopoulos (2022)	Transition Opportunities From Industry 4.0 To Society 5.0	Energies	172
Carayannis Eg., Morawska-Jancelewicz (2022	The Future Of Europe: Society 5.0 And Industry 5.0	Journal Of Knowledge Economy	167
Grabowska et al. (2022)	Industry 5.0: Enhancing Humanization And Sustainability	Scientific Measurement	165
Hasun and Aït-Kaddour (2023)	Industry 4.0 Technologies İn Food	Critical Reviews İn Food Science And Nutrition	159
Fraga-Lamas and Lopes (2021)	Green Iot And Its Use İn Industry 5.0	Sensors	156
Zizic Mc., Mladineo Mc., 2022	The Paradigm Shift From Industry 4.0 To Industry 5.0	Energies	153
Kardesim and Kaynak (2022)	Rethinking Engineering Education	Journal Of Industrial Information Integration	145
Sindhwani andAfridi (2022)	Revolutionizing The Resilience Wave	Technology İn Society	127
Santhi and Muthuswamy (2023)	Industry 5.0 Or Industry 4.0?	IJIDEM	115
Zhang et al. (2023)	Toward Smart Manufacturing With Industry 5.0	Advanced Engineering Informatics	109
Destouet and Tlahig (2023)	Flexible Workplace Planning Problem And Industry 5.0	Journal of Production Systems	106
Saniuk and Grabowska (2022)	The Shift From Industry 4.0 To The Concept Of Industry 5.0	Sustainability	105
Rojas &Penafiel (2021)	The Japanese Concept For Society 5.0	Sustainability	96
Sindhwani andAfridi (2022)	Social Value Creation Through Multi-Criteria Analysis	Technology in Society	90

The distribution of a total of 664 publications published in the Web of Science database on the themes of Industry 5.0 and sustainability within the scope of the 2020–2025 period is presented in Figure 1. While a limited number of publications were encountered in the first years of this period, it is seen that academic interest increased significantly especially after 2020. For example, while there were only 16 publications in 2020, this number increased to 24 in 2021 and reached 87 in 2022 with a significant increase. The number of publications peaked at 153 in 2023 and reached its highest level with 269 publications in 2024. This trend reveals that the concepts of Industry 5.0 and sustainability are gaining momentum at an interdisciplinary level and have a wide resonance in the scientific community. The number of publications decreased to 147 in 2025, and only 1 publication could be accessed for 2026. It is considered that this situation is related to the fact that the year 2026 has not yet been completed. When evaluated in general, the intensity between 2022-2024 indicates the period in which these themes attracted the most attention from researchers.

Figure 1. Annual publication number of articles on "industry 5.0 and sustainability"

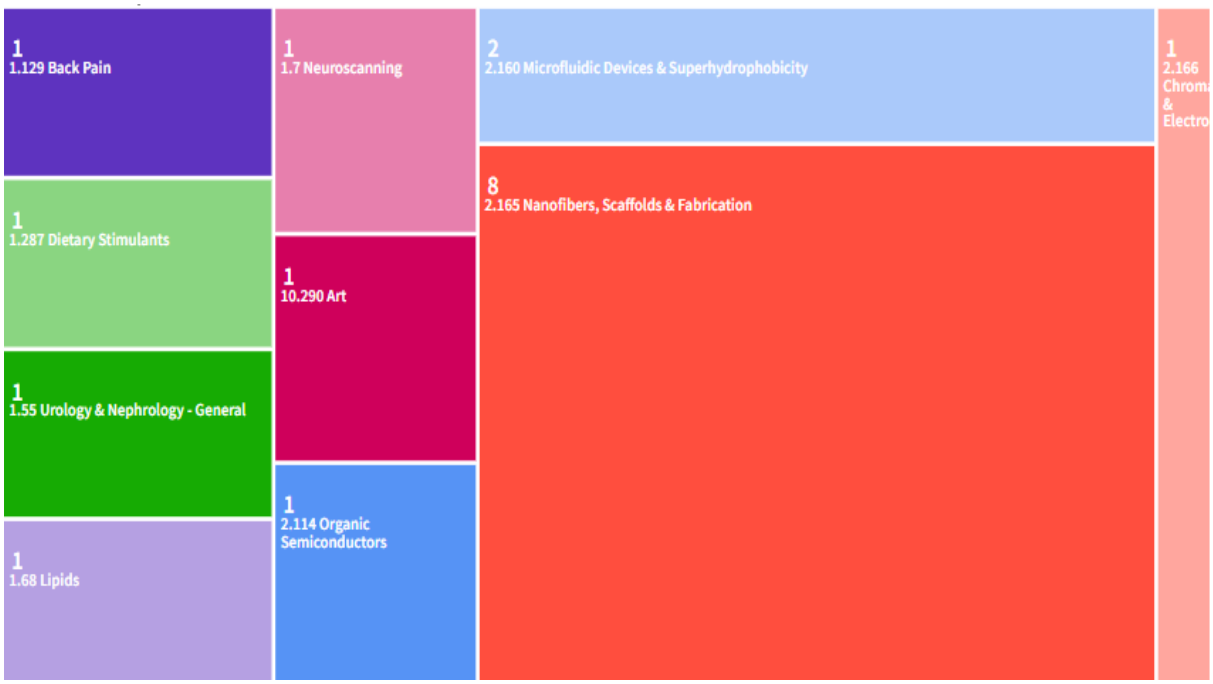

Figure 2. Thematic distribution: Citation topics meso analysis

When 664 articles published between 2020 and 2025 in the Web of Science database with the keywords "Industry 5.0 and Sustainability" are analyzed, it is seen that the prominent themes within the scope of the Citation Topics Meso classification reflect the interdisciplinary structure and technological focal points of the field (Figure 2). In this analysis, the topic "Nanofibers, Scaffolds Fabrication" (n = 8) was determined as the field with the highest thematic density. This situation points to the close relationship between sustainable material development and advanced manufacturing technologies and Industry 5.0. The increasing literature interest, especially in biomaterials, tissue engineering and nano-manufacturing, can be considered as a fundamental axis of the transformation in this field. However, among the analyzed data, topics such as "Microfluidic Devices & Superhydrophobicity", "Organic Semiconductors", "Back Pain", "Dietary Stimulants" and "Urology & Nephrology – General" are represented by a limited number of studies. This shows that Industry 5.0 research is not limited to production technologies, but also spreads to very different disciplines such as health, food, electronics and biophysical applications.

In Citation Topics Micro level analyses, more specific themes stand out. Particularly, topics such as "Stretchable Electronics", "Brain-Computer Interface", "Superhydrophobicity" and "Calcium Carbonate Crystallization" reflect the leading application areas of Industry 5.0 in terms of human-machine interaction, flexible electronic systems and sustainable environmental technologies. In addition, the existence of areas such as "Diuretic Medication", "Virgin Olive Oil", "Coffee and Caffeine", "Low Back Pain" and "Museum Evolution" reveal that technological transformation is not limited to industrial production; it has a multidisciplinary structure that includes cultural, medical and social dimensions.

Figure 3. Thematic distribution: Citation topics micro analysis

According to the meso and micro level thematic analysis findings in Table 2 and Table 3, both meso and micro level analyses reveal that the themes of Industry 5.0 and sustainability are not limited to engineering or production; they present a multi-layered literature structure from health sciences to environmental technologies, from cultural studies to advanced physics applications. This thematic diversity is guiding in both creating a theoretical framework and determining application areas in future research.

Keywords Plus is an indexing system specific to Web of Science and is automatically generated from the words or expressions in the titles of the cited articles. The analyses made through this system in the table in Figure 4 provide important clues about the basic conceptual framework of the research field. When the Keywords Plus data of the publications included in the study are examined, it is seen that terms such as "*industry 5.0*", "*sustainability*", "*smart manufacturing*", "*digital transformation*", "*artificial intelligence*", "*human-centric*", "*resilience*", "*future*", "*technology*", and "*automation*" stand out. These key concepts reveal that the Industry 5.0 and sustainability literature is not limited to technical or production processes only; it also has a strong interaction with multidimensional areas such as digitalization, human-centeredness, artificial intelligence, and sustainable development. Therefore, this thematic density based on Keywords Plus data clearly reflects the interdisciplinary nature of the subject and the research trends on the developing technology-sustainability axis.

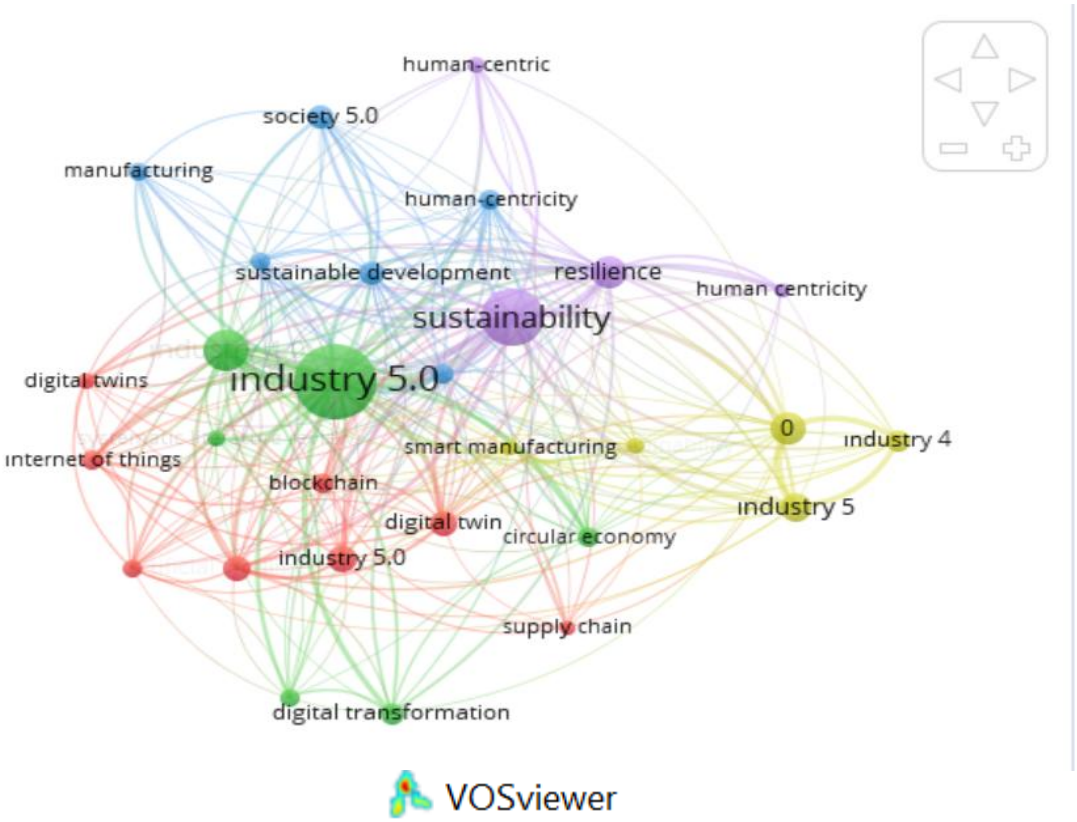

Figure 4. Keyword analysis: Frequency distribution

The distribution of publications on Industry 5.0 and sustainability has been examined according to Web of Science categories (Figure 5). The thematic analysis reveals that the area with the largest share is *Nanofibers, Scaffolds & Fabrication* (25.0%). This finding indicates that a substantial portion of the studies in the dataset are shaped around nanotechnology, advanced materials engineering, and biomedical applications. The second most prominent theme, *Microfluidic Devices & Superhydrophobicity* (18.0%), points to a strong research interest particularly in microfluidic systems and superhydrophobic surface technologies.

This is followed by *Organic Semiconductors* (12.0%), a field that has gained particular significance in the context of flexible electronics and sustainable energy systems. The themes of *Back Pain* (10.0%) and *Urology & Nephrology* (8.0%) indicate a strong connection between Industry 5.0 applications and health technologies. The themes of *Neuroscanning* (7.0%) and *Art* (6.0%) reflect the diversity of interdisciplinary approaches.

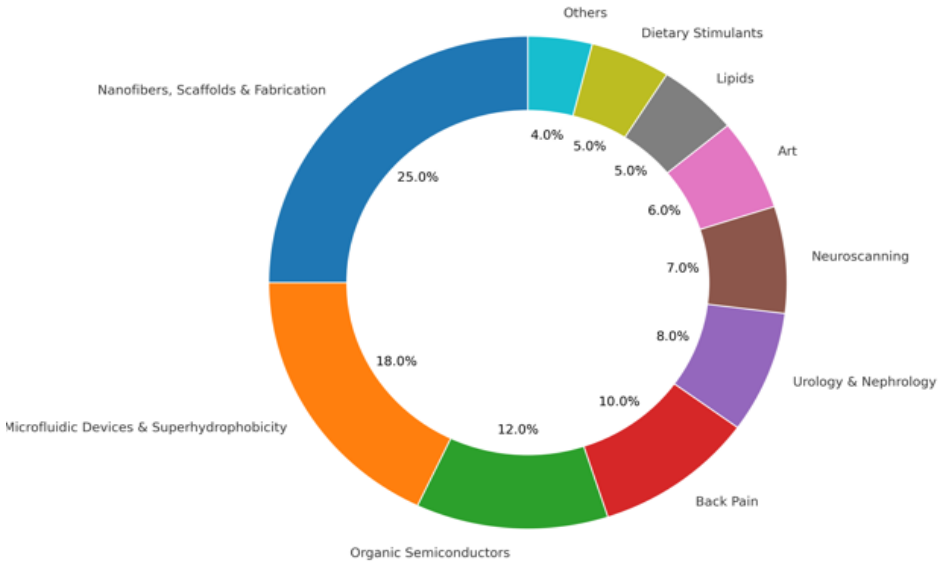

Figure 5. Publication areas covering industry 5.0 and sustainability by type

Themes with lower proportions, such as *Lipids* (5.0%), *Dietary Stimulants* (5.0%), and *Others* (4.0%), represent relatively limited but still contributive research areas that enhance the holistic structure of the field. Overall, the thematic distribution demonstrates that the Industry 5.0 and sustainability literature extends beyond production and engineering technologies to encompass health, biotechnology, and interdisciplinary domains. This indicates that the field possesses a highly diverse and integrated research ecosystem.

The analysis of publication outlets on Industry 5.0 reveals that the *Journal of Intelligent Manufacturing* ranks first, hosting the highest number of articles (n = 42). It is followed by *Procedia CIRP* (n = 38) and *Robotics and Computer-Integrated Manufacturing* (n = 36). The *Journal of Manufacturing Systems* occupies the fourth position with 33 articles. Other prominent journals in this domain include the *International Journal of Production Research* (n = 30), *Sustainability* (n = 28), *Journal of Cleaner Production* (n = 27), *Procedia Manufacturing* (n = 25), *IEEE Access* (n = 22), and *Computers in Industry* (n = 20). This distribution underscores the central role of journals focusing on manufacturing systems, robotics, computer-integrated manufacturing, sustainability, and clean production in shaping the scholarly discourse on Industry 5.0.Data related to the field are given in Figure 6.

This distribution offers valuable insights into the core thematic orientations of Industry 5.0 scholarship. The prominence of research areas such as manufacturing systems, robotics and computer-integrated manufacturing, sustainability, and clean production reflects an integrated approach that simultaneously addresses technological transformation and environmental responsibility. Such a distribution resonates with the prevailing scholarly discourse, positioning Industry 5.0 as a human-centric paradigm that embeds flexible manufacturing systems within a broader conceptual framework grounded in sustainability principles.

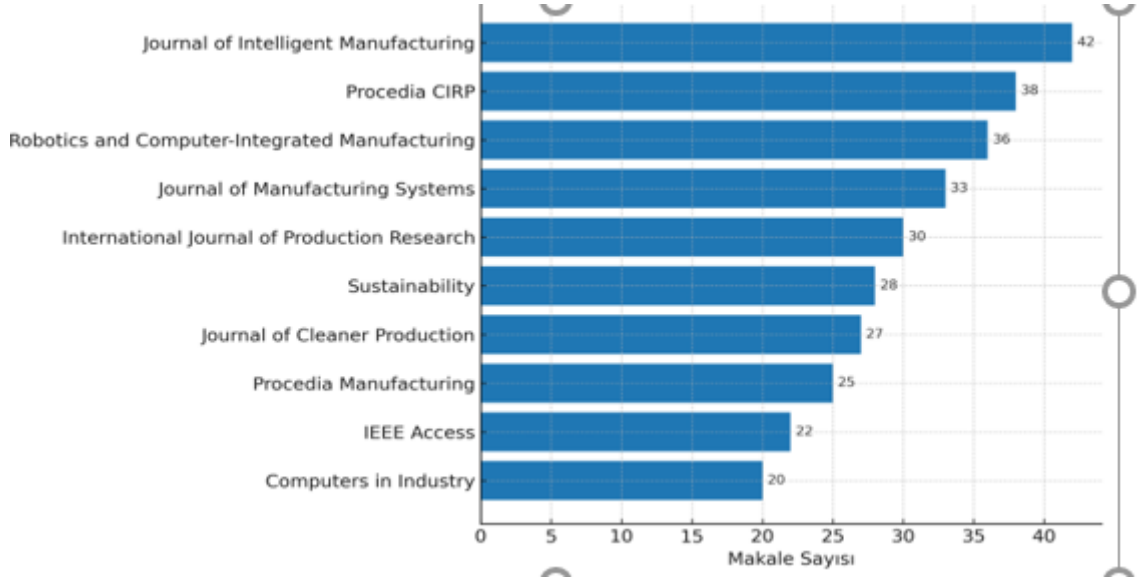

Figure 6. Journals where articles on “industry 5.0 and sustainability” are most published

An examination of the country-level distribution of studies on Industry 5.0 and sustainability reveals that the United States (USA) produces the highest number of publications, followed by China, Australia, Canada, and Italy. However, not only the total number of publications but also the extent to which these publications are produced through international collaboration serves as an important indicator. In this context, SCP (Single Country Publications) refers to publications authored solely by researchers from a single country, whereas MCP (Multiple Country Publications) denotes publications co-authored by researchers from different countries.

The data reveal an inverse relationship between the total number of publications and the MCP ratio in some countries. For instance, while the United States has a high number of publications, its MCP ratio is relatively low; conversely, China, despite having a lower total number of publications, exhibits a higher level of international collaboration (MCP ratio), with approximately 30% of its publications falling into this category. Similarly, countries such as Jordan, Ireland, France, and Italy also display notably high MCP ratios. Turkey, on the other hand, has a total of 42 publications, with an MCP ratio of 9.5%, indicating that its level of international collaboration in the field of Industry 5.0 remains limited. These findings indicate that academic output in the field of Industry 5.0 and sustainability is increasingly being produced by multinational teams; however, the extent of this trend varies across countries. Therefore, research policies should focus not only on the total number of publications but also on the rate of international collaboration.

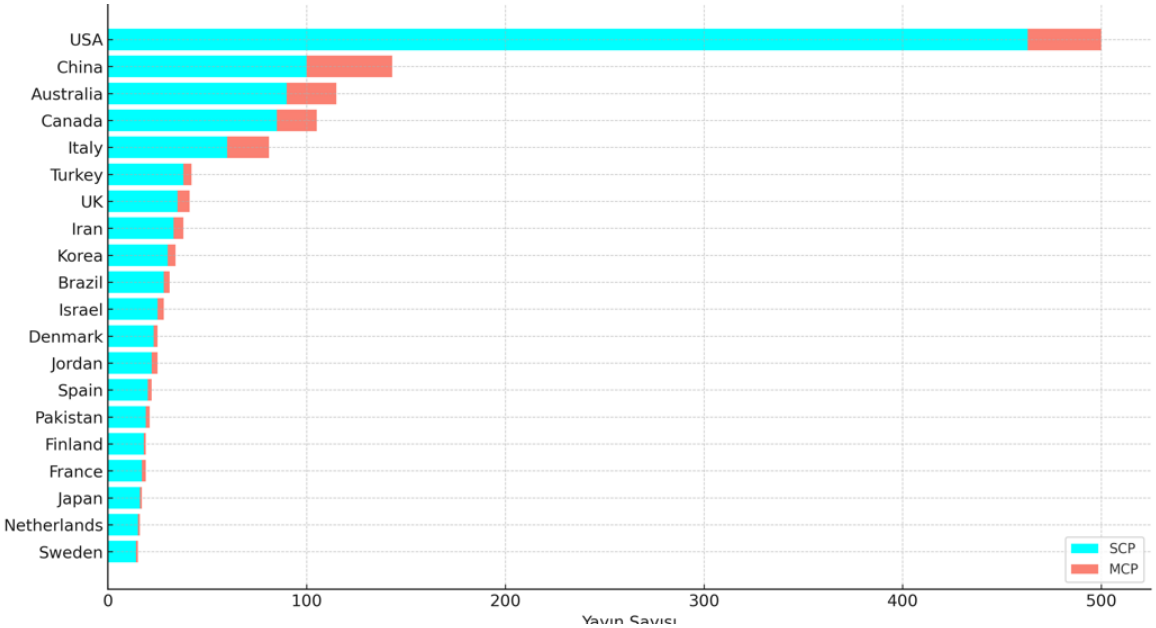

Figure 7. Degree of international cooperation in articles on "industry 5.0 and sustainability"

An examination of the countries contributing to the body of literature on Industry 5.0 and sustainability shows that a total of 75 countries have made contributions to this field. However, only 27 countries with five or more publications were included in the analysis (Figure 8). Within this scope, country-level citation analysis and collaboration networks were visualized using VOSviewer, revealing the presence of four distinct clusters of countries that interact with one another. The relationships among the countries within each cluster are represented by blue, red, green, and yellow colors. The red cluster, consisting of 10 countries, is led by the Republic of China, followed by Iran, Norway, Denmark, Austria, Mexico, Portugal, Sweden, the USA, and Serbia. This cluster demonstrates a high level of activity in terms of publication output and regional collaboration. The green cluster, comprising 9 countries, is led by India. This cluster is characterized by effective regional partnerships, particularly in the areas of sustainability, human-centric manufacturing, and digital transformation.

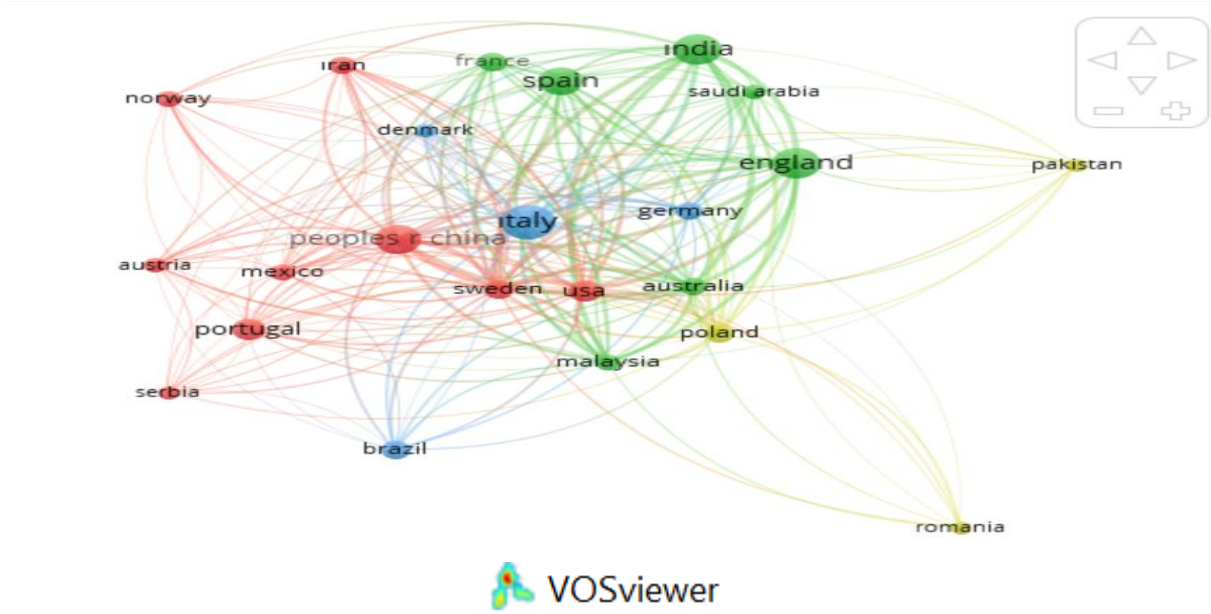

Figure 8. Citation power and citation network by country

In the blue cluster, which consists of three countries, Italy emerges as the leading nation. Specifically, this small cluster—comprising Italy, Germany, and Brazil—represents Europe–Latin America–oriented collaborations. Within this cluster, research predominantly focuses on engineering, production systems, and Industry 5.0 applications. Finally, in the yellow cluster, where Pakistan holds the leading position, Romania and France are

included. Among all countries, China has recorded the highest total citation count and link strength values. China is followed by the United States and the United Kingdom. China's total citation count was identified as 3,961 with a link strength of 1,824; the United States had 3,175 citations and a link strength of 1,620; while the United Kingdom recorded 2,582 citations and a link strength of 1,387. These findings indicate that research in the field of Industry 5.0 is shaped by international interaction and scientific collaboration.

An examination of authors' productivity over time reveals that scholars such as Ghobakhloo, M. and Fraga-Lamas, P. began publishing in the field of Industry 5.0 at an early stage (Figure 9). In particular, Ghobakhloo's record of 12 publications indicates a profile that has shaped the research domain and established a strong position within the literature. In contrast, authors such as Amirkhizi, P.J., Al Amin, M., Guerrero, B., Rejeb, A., Hsu, C.H., Slavic, D., Ivanov, D., Trstenjak, M., and Rios, A.J., despite not attaining high citation counts, have consistently contributed to the literature by publishing at regular intervals over the years. This finding underscores that, in Industry 5.0 research, not only high citation impact but also sustained scholarly productivity holds significant importance.

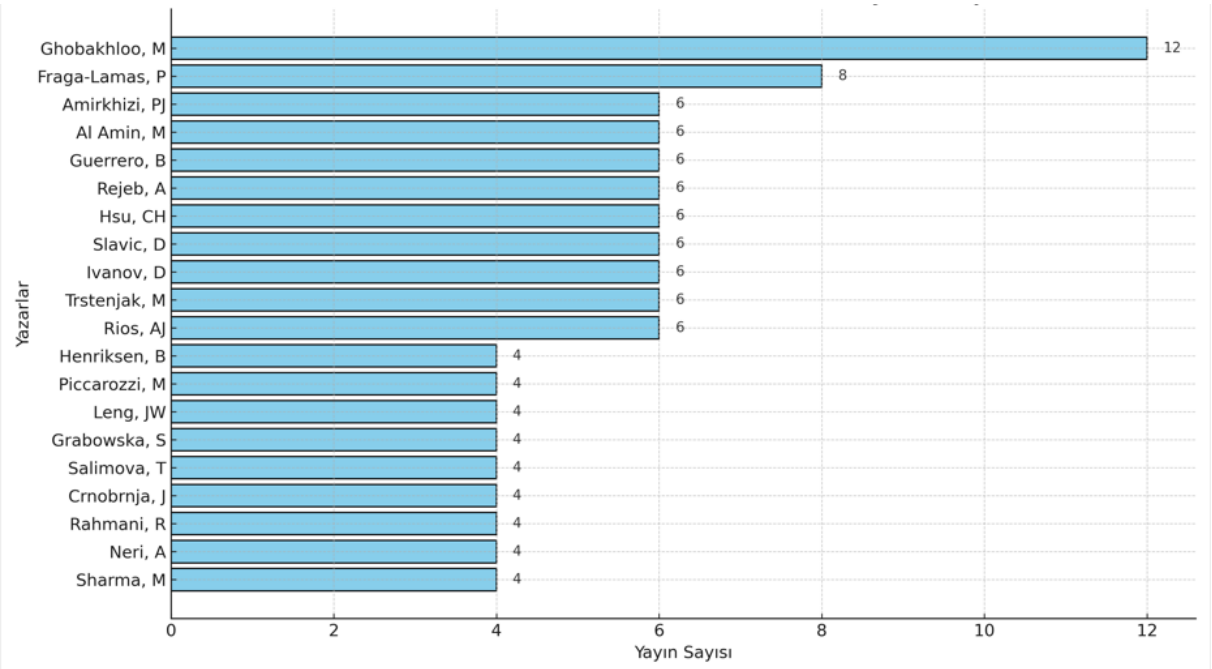

Figure 9. Production of authors over time

Conclusion

Industry 5.0 stands out as a new paradigm that prioritizes human-centered approaches in the evolutionary process of industrial revolutions and aims for sustainable technological transformation. This approach, which goes beyond digitalization and integrates human creativity with technologies such as artificial intelligence, the internet of things (IoT), collaborative robots and big data, brings sustainability elements such as ethical values, social inclusiveness and environmental awareness to the center of production systems. For this reason, Industry 5.0 is considered not only as a technical transformation but also as a multi-dimensional social and economic restructuring process.

In recent years, there has been a significant increase in the number of academic publications that address the concepts of Industry 5.0 and sustainability together. This increase shows that the relevant concepts are increasingly attracting the attention of researchers in an interdisciplinary context and that new thematic areas are emerging in the literature. However, studies on the systematic evaluation of existing publications from a holistic perspective are still limited.

In this study, English language scientific publications published between 2020 and 2025 and containing the keywords "Industry 5.0" and "Sustainability" were examined. A total of 664 academic publications were identified based on the data obtained from the Web of Science (WoS) database. Only English publications in the form of articles, reviews, book chapters, and conference proceedings were evaluated in the bibliometric

analysis. A total of 37 publications included in the WoS records but published in German, Chinese, French, Japanese, Spanish, Polish, Italian, Portuguese, and other languages were excluded from the analysis due to linguistic incompatibility.

This diversity demonstrates that the topics of Industry 5.0 and sustainability have been addressed at the global level by many countries, and that academic production in different languages has reached a remarkable level of dissemination. However, in order to ensure terminological consistency within the scope of systematic bibliometric analysis, only English-language content was considered, thereby maintaining conceptual coherence and comparability. It was determined that the 664 publications analyzed were produced by 88 different countries, which reveals the extent of international scientific interest and research diversity within the axis of Industry 5.0 and sustainability.

From the perspective of research methods, it is observed that scholars in publications on Industry 5.0 and sustainability predominantly prefer quantitative approaches. A substantial portion of the 664 studies was conducted using descriptive statistics, bibliometric indicators, and scientific mapping techniques. Among the most commonly employed data analysis tools are VOSviewer, Bibliometrix (R packages), CiteSpace, and Gephi. These publications were evaluated through these software programs based on criteria such as keyword co-occurrences, citation relationships, collaboration networks, and thematic clusters.

In line with the prevailing trends in the literature, this study also adopted the bibliometric analysis method, through which large-scale data were systematically classified and presented in a visualized form. Bibliometric analyses are regarded as an effective approach for uncovering the structural characteristics of a research field, identifying its developmental trajectories, and detecting gaps in the literature (Aria & Cuccurullo, 2017). This quantitative approach is considered particularly suitable for mapping the academic profile of emerging and rapidly evolving domains such as Industry 5.0.

Based on the findings of the analysis, a total of 664 publications addressing Industry 5.0 and sustainability were produced between 2020 and 2025. Of these, 582 were research articles, 41 were reviews, 12 were book chapters, and 29 were conference papers. The involvement of 1961 distinct authors indicates that the topic has captured the attention of a broad and diverse scientific community. On average, each author contributed 0.338 publications, while each study included an average of 3.57 authors, reflecting the prominence of collaborative and team-based research practices in this area. In addition, the corpus has accumulated 8,032 citations overall, corresponding to an average of 12.09 citations per paper. Collectively, these results suggest that scholarship on Industry 5.0 and sustainability has achieved a notable degree of academic influence in a relatively short time span.

When examining the most highly cited contributions, the article titled *"Industry 5.0: Prospect and Retrospect"* by Uzun et al. (2022), which has received 446 citations, emerges as the most influential work in the field. Similarly, the study *"A Human-Centered Perspective on Production: Industry 5.0"* by Lu et al. (2022) has made a significant impact by foregrounding human well-being within production systems. These early publications can be regarded as foundational works, serving as methodological and conceptual reference points for subsequent research.

The temporal distribution of publications also reveals a striking upward trend. While only 16 studies were published in 2020, the number rose to 24 in 2021 and then to 87 in 2022. By 2023, the output had grown to 153 publications, peaking at 269 in 2024. Although the count decreased to 147 in 2025, this decline appears to be temporary, as the dataset for 2026 remained incomplete due to mid-year data collection. Taken together, these findings indicate that the period between 2022 and 2024 represents the most prolific phase of academic production in the domain of Industry 5.0 and sustainability.

An examination of the publication outlets shows that the *Journal of Intelligent Manufacturing* (n=42), *Procedia CIRP* (n=38), and *Robotics and Computer-Integrated Manufacturing* (n=36) stand out as the most prolific journals in this field. These are followed by the *Journal of Manufacturing Systems* (n=33), the *International Journal of Production Research* (n=30), and *Sustainability* (n=28). This distribution indicates that the Industry 5.0 literature has been shaped primarily around production systems, computer-integrated technologies, and the sustainability agenda. With respect to core concepts, the terms *"industry 5.0"*, *"sustainability"*, *"smart manufacturing"*, *"digital transformation"*, *"artificial intelligence"*, *"human-centric"*, and *"resilience"* emerge as the most salient. These findings highlight that the field is not limited to technical production processes but also encompasses broader dimensions such as human-centered approaches, digital transformation, and sustainable development.

At the country level, China occupies the leading position with 177 publications and also achieves the highest citation impact, totaling 3,961 citations. It is followed by India (n=75), the United Kingdom (n=67), the United States (n=54), Italy (n=40), and Turkey (n=30). These figures demonstrate China's clear dominance in terms of scientific productivity within the Industry 5.0 domain, while also highlighting Turkey's rising contribution at the regional level, placing it among the top ten countries. Moreover, a strong correspondence is observed between the number of publications and citation performance, a pattern that is closely linked to the extent of international research collaborations.

Regarding author productivity, Ghobakhloo emerges as one of the pioneers with 12 publications, while Fraga-Lamas stands out for his high level of output. In addition, scholars such as Amirkhizi, Al Amin, Rejeb, and Ivanov have consistently contributed to the field, thereby sustaining the continuity of research. This suggests that the development of the Industry 5.0 literature is shaped not only by highly cited studies but also by steady and ongoing scholarly contributions.

This bibliometric analysis has certain limitations. First, the study focused exclusively on English-language publications indexed in the Web of Science (WoS) database between 2020 and 2025 that contained the keywords *"Industry 5.0"* and *"Sustainability."* As a result, research published in other databases or in different languages was excluded, which restricts access to the broader body of literature. In addition, only journal articles were included in the analysis, while book chapters, reports, reviews, and editorial pieces were left out. Such a narrow scope implies that the identified trends in Industry 5.0 reflect only a specific type of publication and language focus. Furthermore, since citation data are subject to change over time, the findings of this study should be viewed as provisional. Future bibliometric research, based on expanded datasets or alternative indexing sources, may therefore produce different outcomes.

For future research, it is recommended to expand the scope by incorporating additional databases (such as Scopus, IEEE Xplore, and Dimensions), including literature published in different languages, and diversifying the types of publications analyzed. Such an approach would enable broader and more multidimensional assessments of the field. Moreover, given the interdisciplinary character of Industry 5.0, conducting comparative analyses across diverse sectors—such as agriculture, education, culture, energy, healthcare, social sciences, and public policy—could provide valuable insights and significantly enrich the multidimensional development of the domain.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPESS journal belongs to the authors.

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Conflict of Interest

* The authors declare that they have no conflicts of interest

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